Broadband polarization-independent antireflection coatings for solar cells from Mie resonators in silicon metasurfaces

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Chief Science Officer
Metamaterial Technologies Inc.

Outline

- About MTI
- The Problem
- metaSolar
- Semiconductor AR Coatings
- Manufacturing

About MTI

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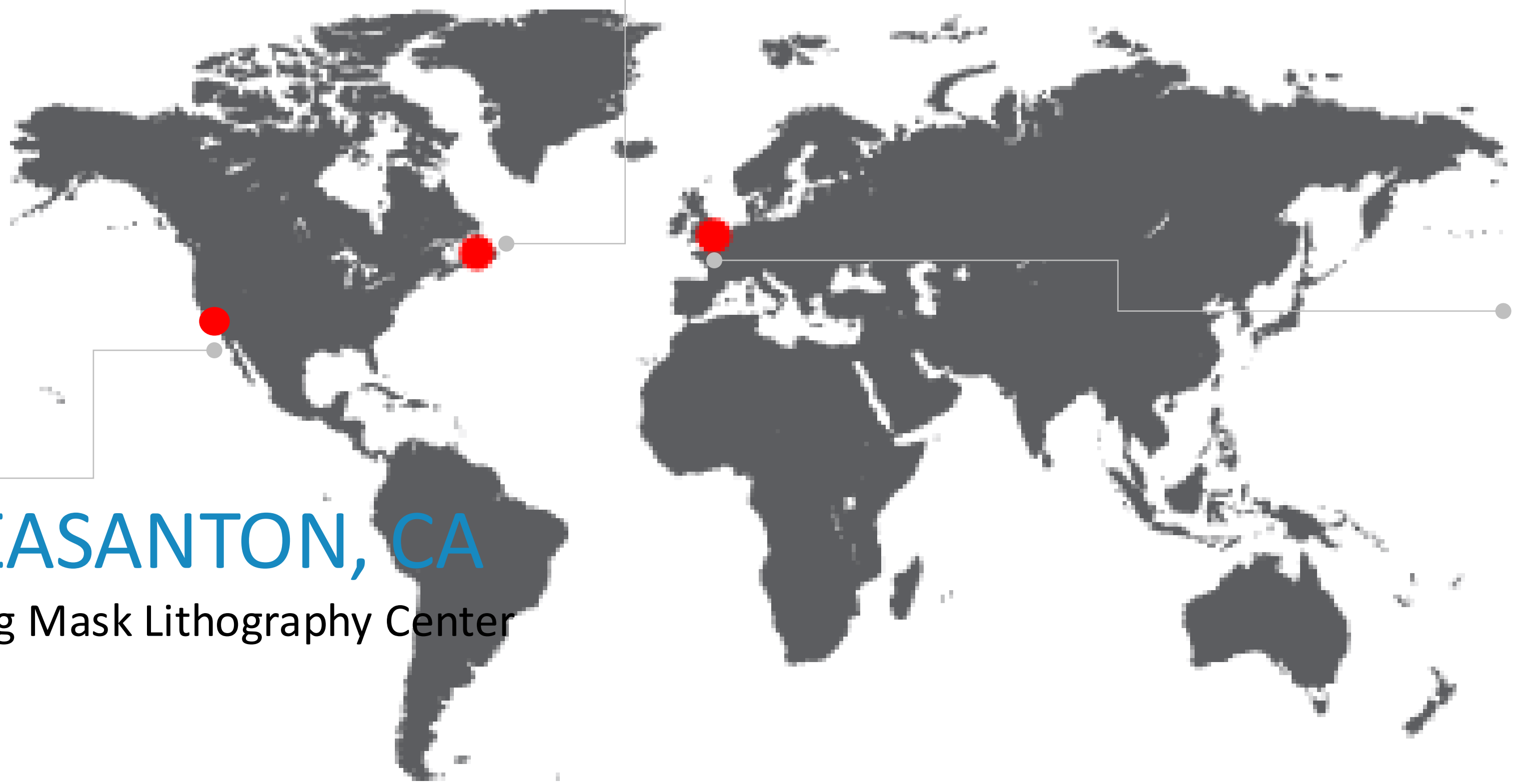
Mastering Light



HALIFAX, NS
MTI head office

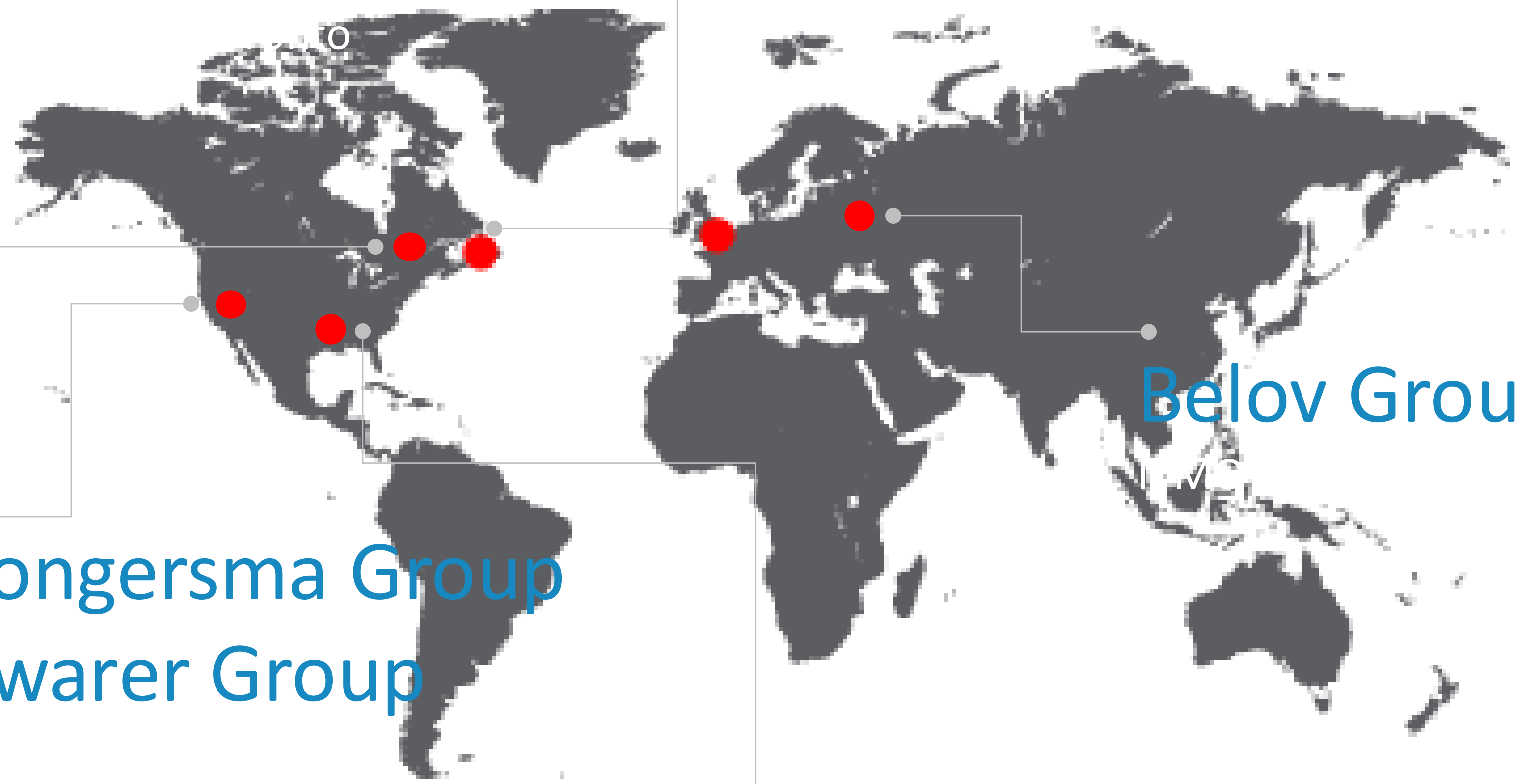
LONDON, UK
R&D and EU Sales Office

PLEASANTON, CA
Rolling Mask Lithography Center

Founded in 2010
35 People
20 Patent Families
metamaterial.com

Elefteriades Group

Caloz Group



Belov Group

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THE UNIVERSITY OF TEXAS AT AUSTIN

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The Problem

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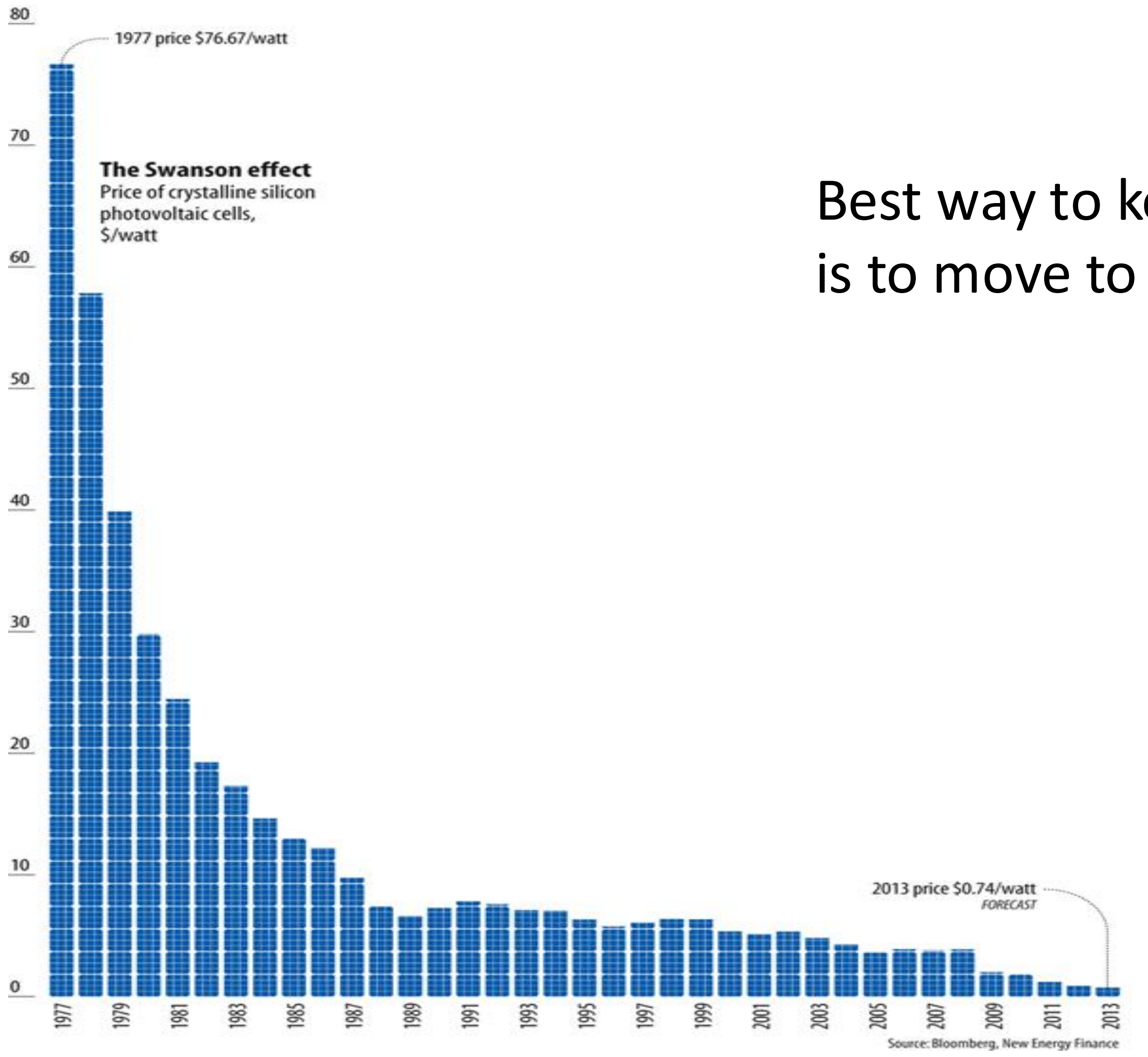
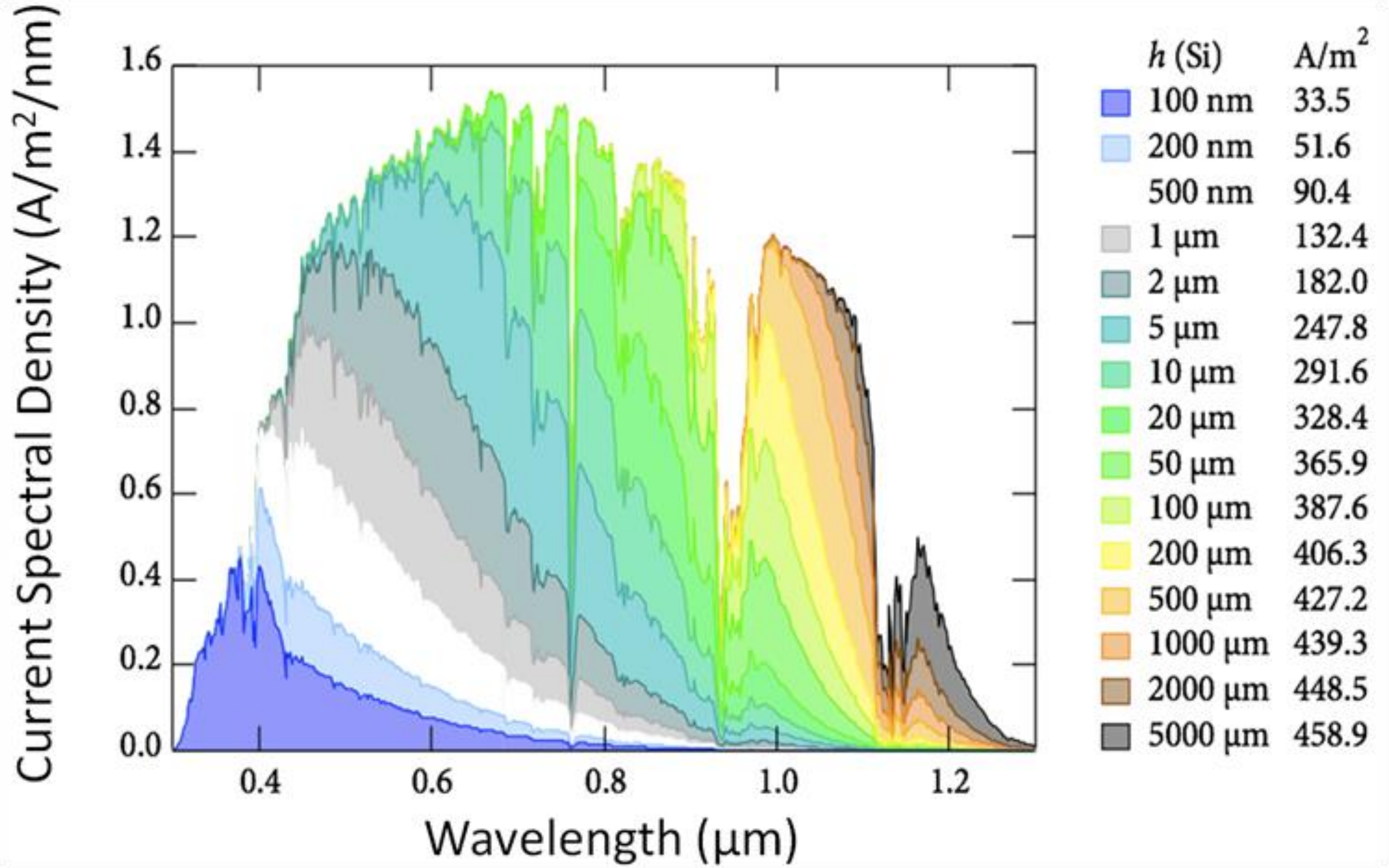
Motivation

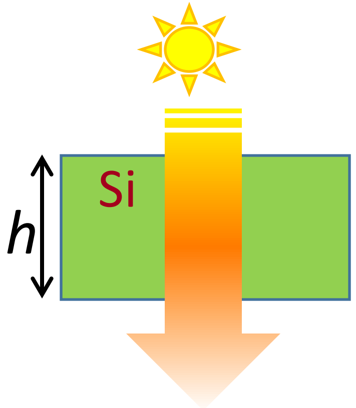


Best way to keep reducing price of cSi
is to move to thinner, more efficient cells.

Thin Cells: Limited Single Pass Absorption

Example: *Single-pass absorption of light in a Si wafer illuminated with the AM 1.5 solar spectrum*





- Fraction of absorbed sunlight rapidly decreases with decreasing thickness
- We need very good light trapping layers to enhance the absorption of sunlight per unit volume

Thin Cells: 10 μm results

ARTICLE

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All-back-contact ultra-thin silicon nanocone solar cells with 13.7% power conversion efficiency

Sangmoo Jeong[1], Michael D. McGehee[2] & Yi Cui[2,3]

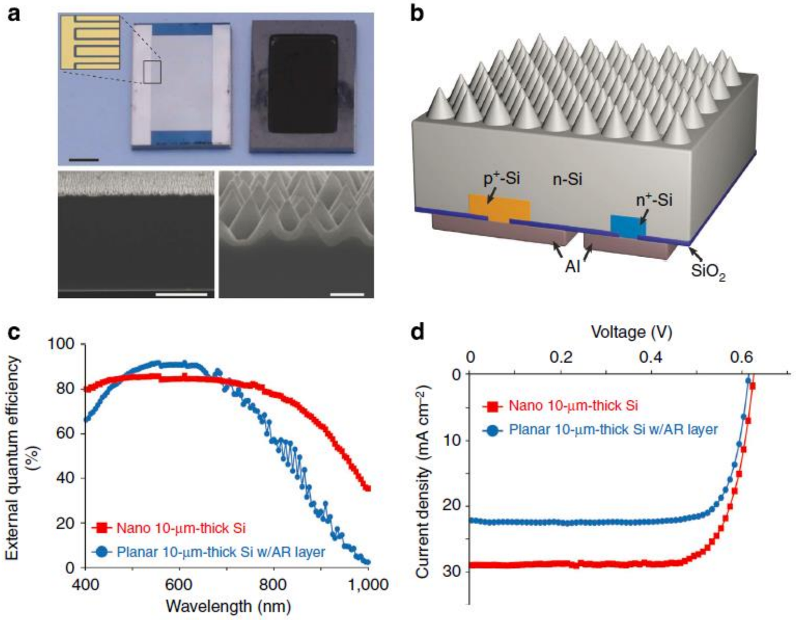

Figure 1 | Ultra-thin Si nanocone solar cell. (**a**) Optical image of the back (top, left) and front (top, right) side of the 10-μm-thick Si solar cell. Inset shows the optical microscope image of the interdigitated metal electrodes. SEM images of cross-sectional view of the device (bottom, left) and cross-sectional view of the nanocones (bottom, right). The thin layer at the top of the nanocones is an 80-nm-thick SiO_2 layer. Scale bars are 2 mm (top), 5 μm (bottom, left) and 400 nm (bottom, right). (**b**) Schematic illustration of the device. (**c**) EQE data of the device and a planar control. (**d**) *J–V* characteristics of two devices in **c**.

About metaSolar

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Building on the Success of Silicon HIT Cells

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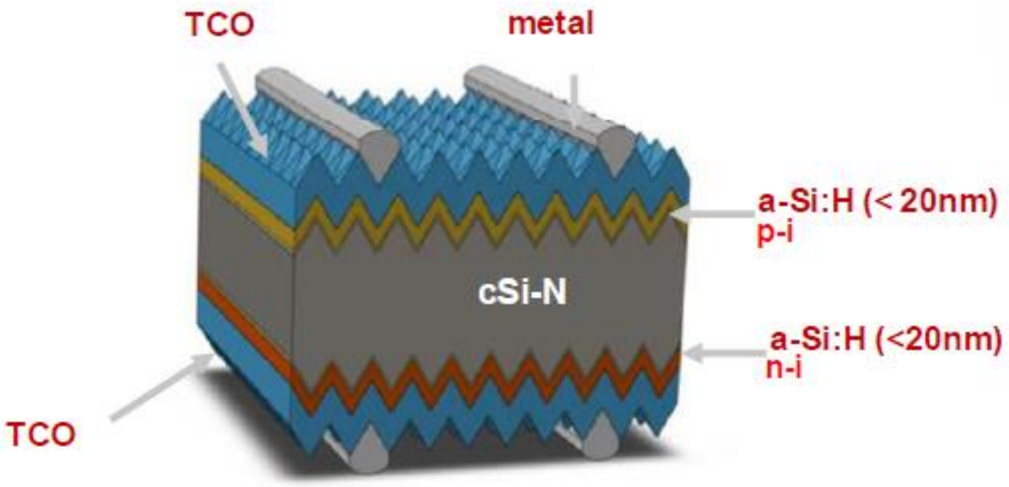
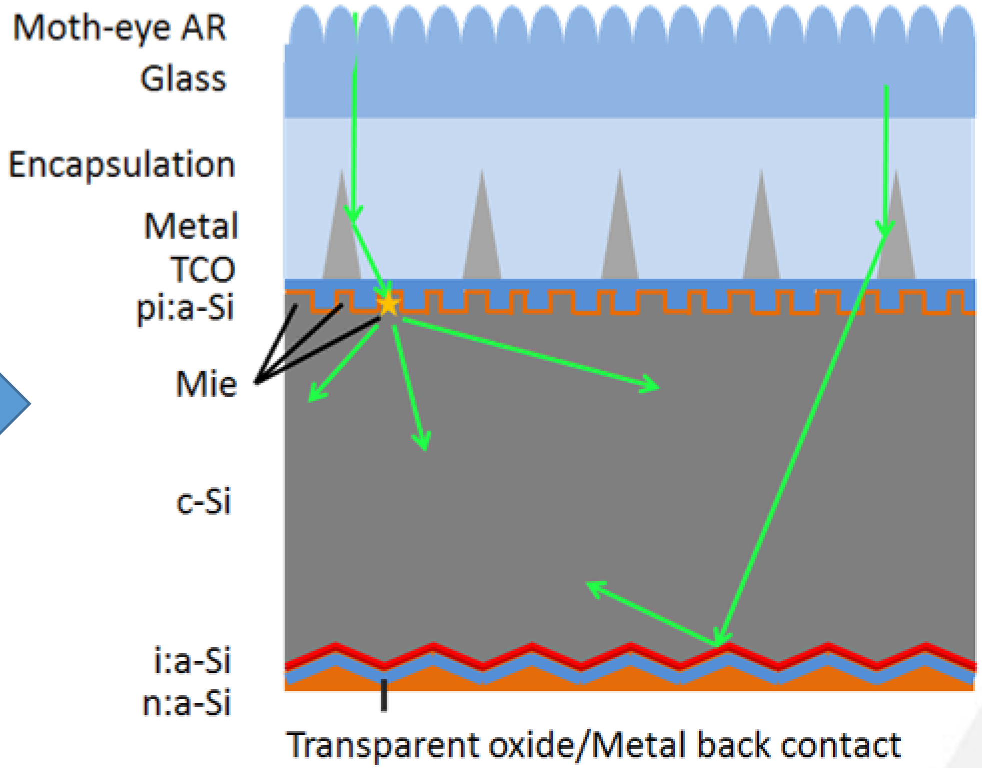
Current Si Heterojunction Cells



metaSOLAR HIT Cell Design



metaSOLAR features:

- Reducing c-Si layer to 50µm
- Moth-eye structures as omni-directional anti-reflection coatings on glass
- New transparent metal electrodes
- **Mie scatterers on top surface for anti-reflection and light trapping**

Anti-Reflection Approaches

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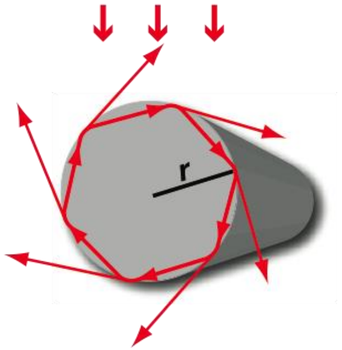
- Adiabatic transition of the refractive index from the superstrate to the substrate
  - Random chemical etching to roughen and texture the substrate surface
  - Nanostructures such as nanowires or nanocones)
- Impedance matching through the design of metal optical nanoantenna.
- **Mie semiconductor resonators to manipulate and trap light**

Resonant Semiconductor Nanostructures

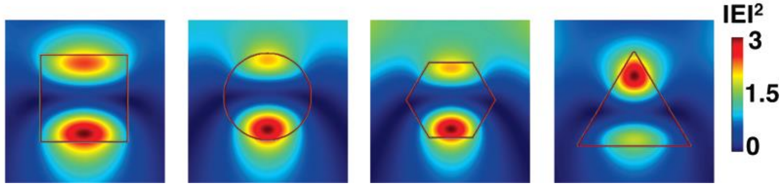
Light storage



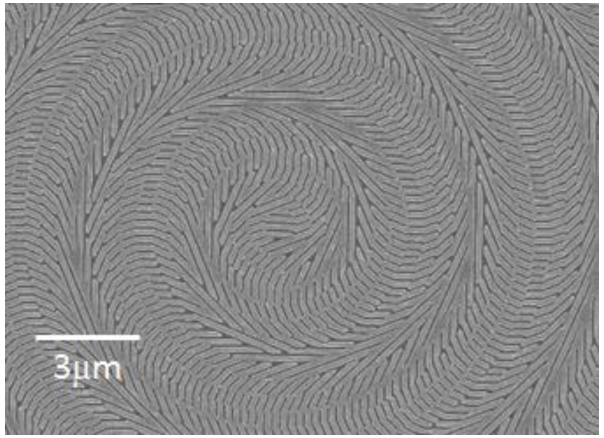
Resonance Condition

$$m\lambda_{eff} = 2\pi r$$

Tuning of light scattering

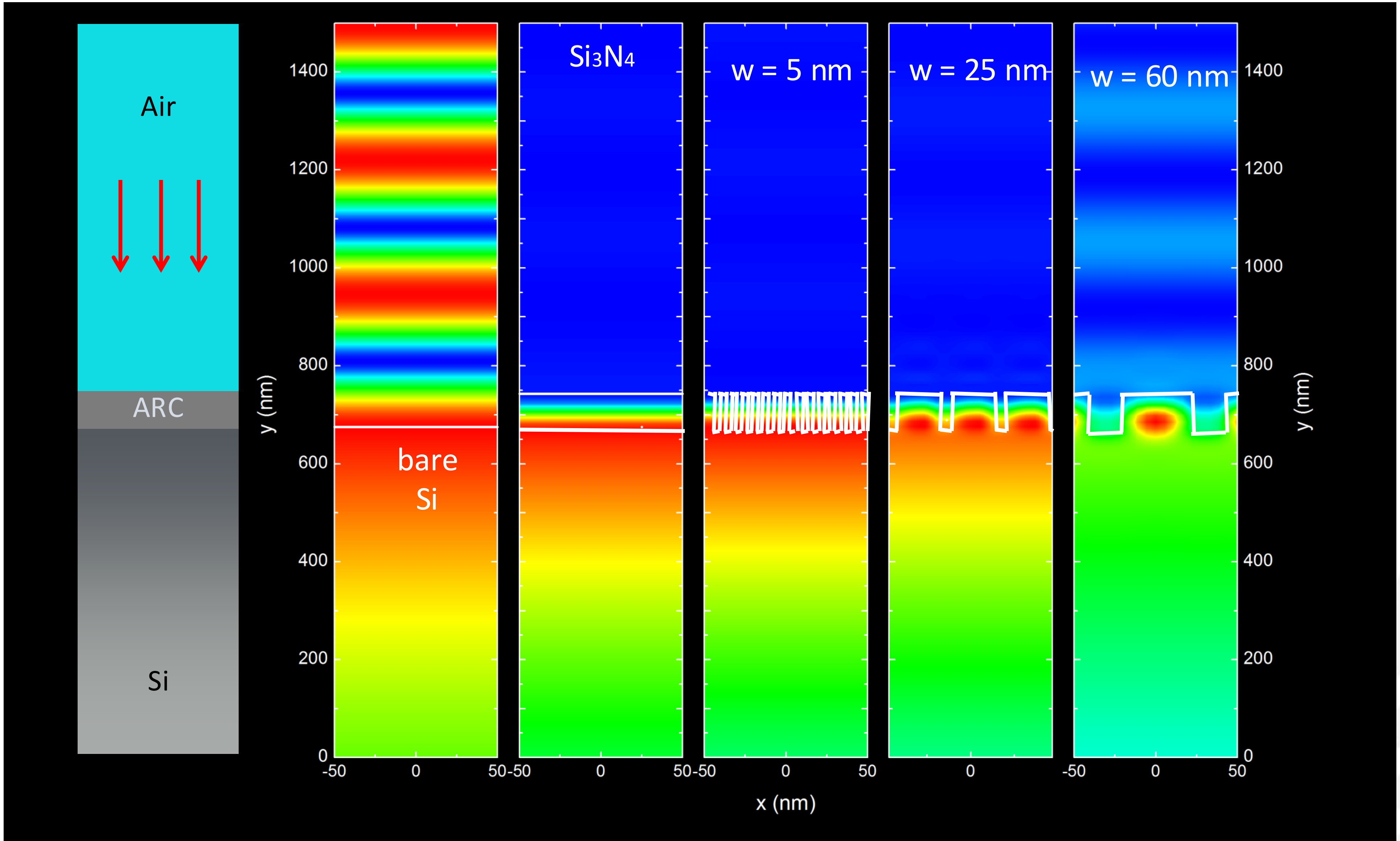


Engineering optical resonance frequency with shape

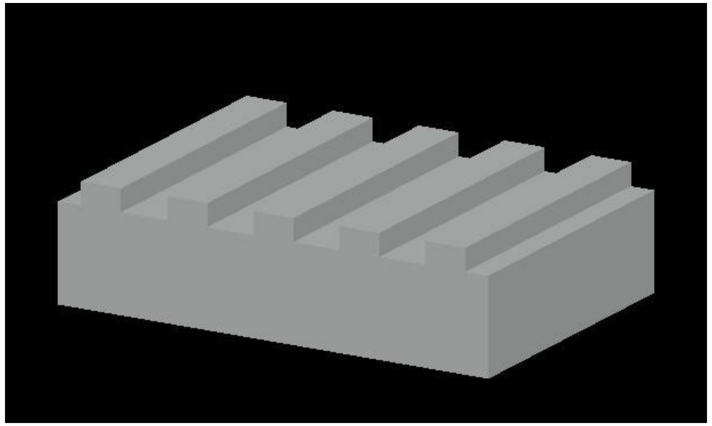


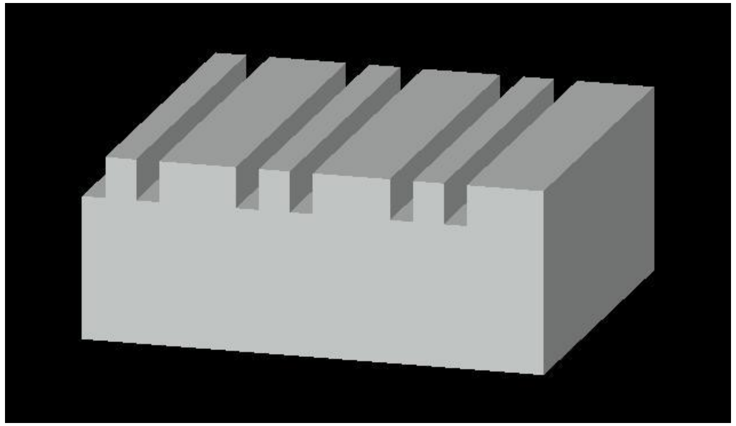
Cao, et al., Nano Lett., 2649, 10, 2010/ *Ho-Seok Ee et al., Nano Letters, 15, 1759, 2015/* Dianmin Lin et al., Science, 298, 345, 2014

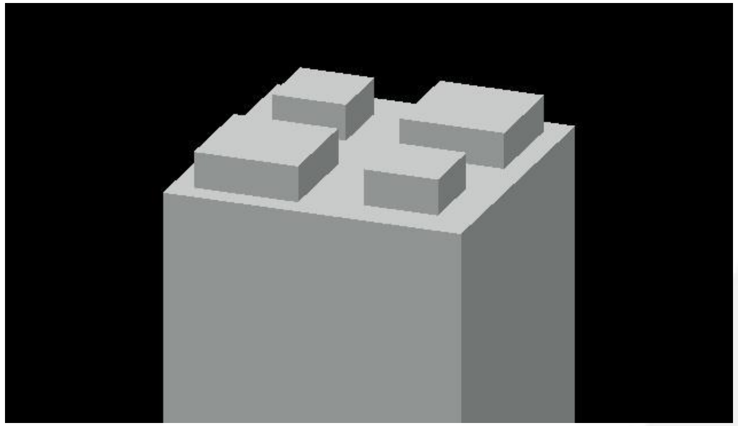
Transition from a Non-resonant to a Resonant AR Coating



Semiconductor AR Structures







Nanowire AR Coatings

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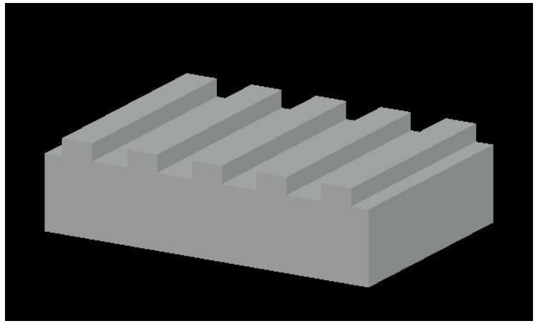
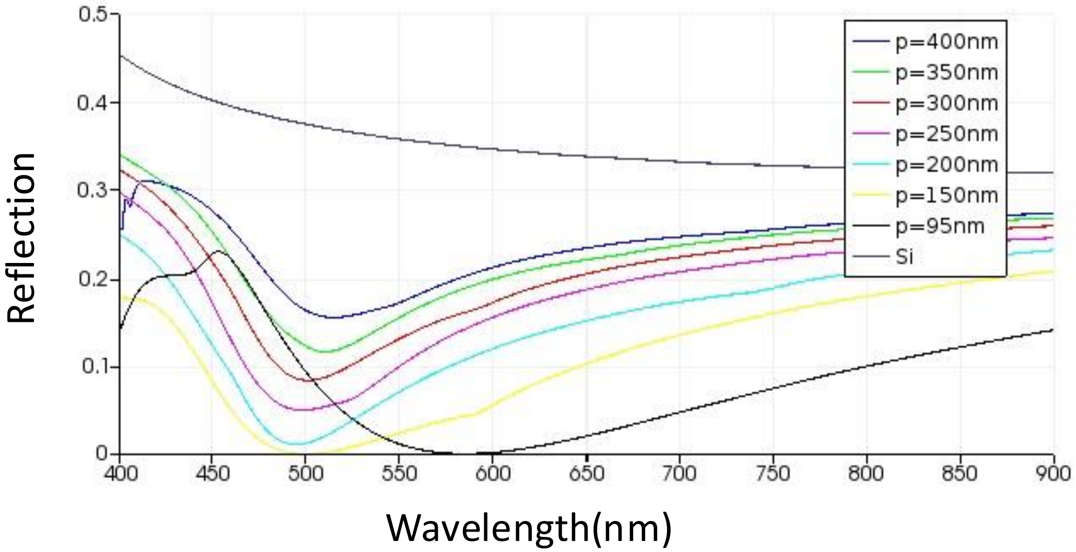
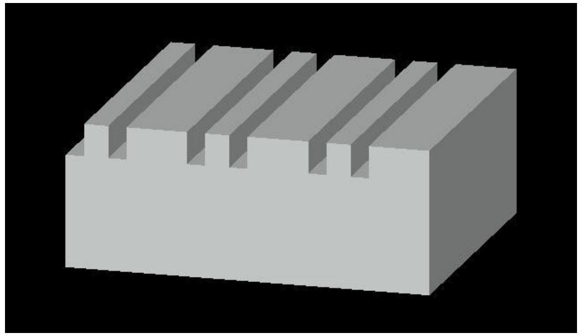
Monomodal



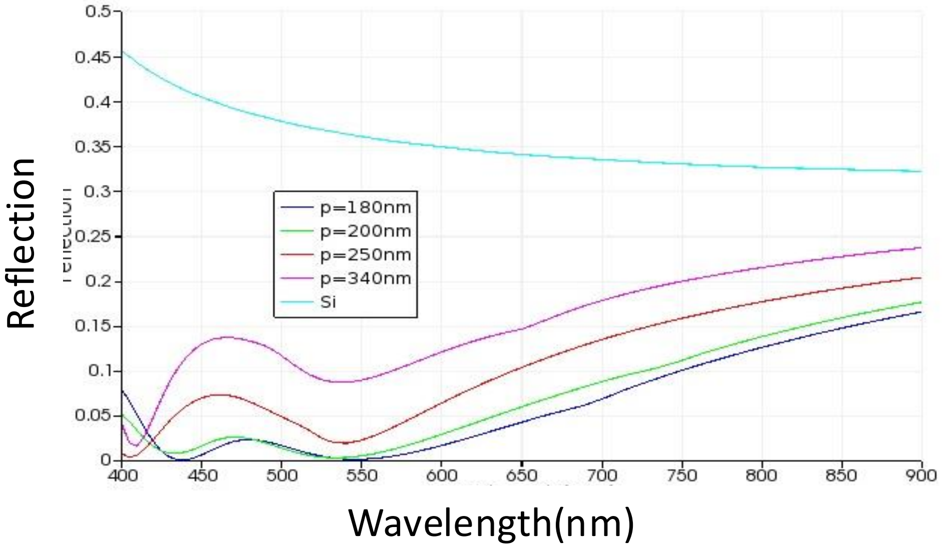
w = 70nm, t=70nm



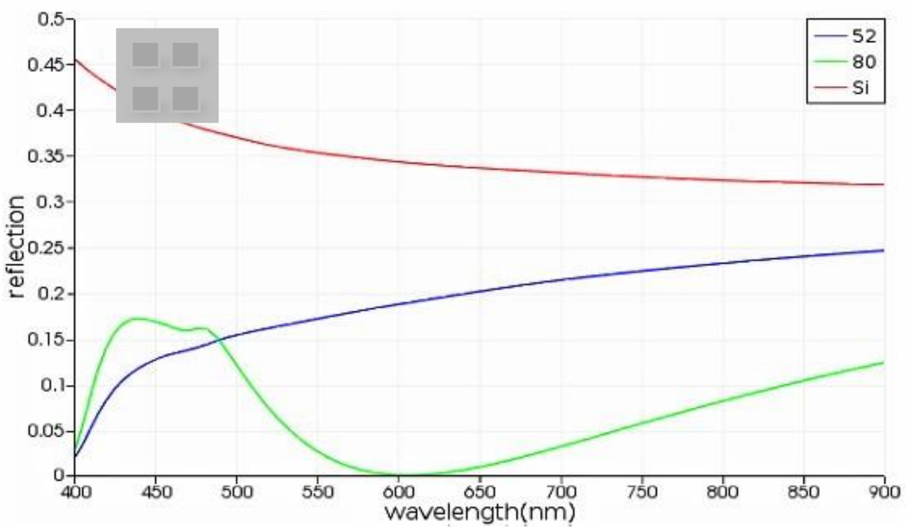
Bimodal



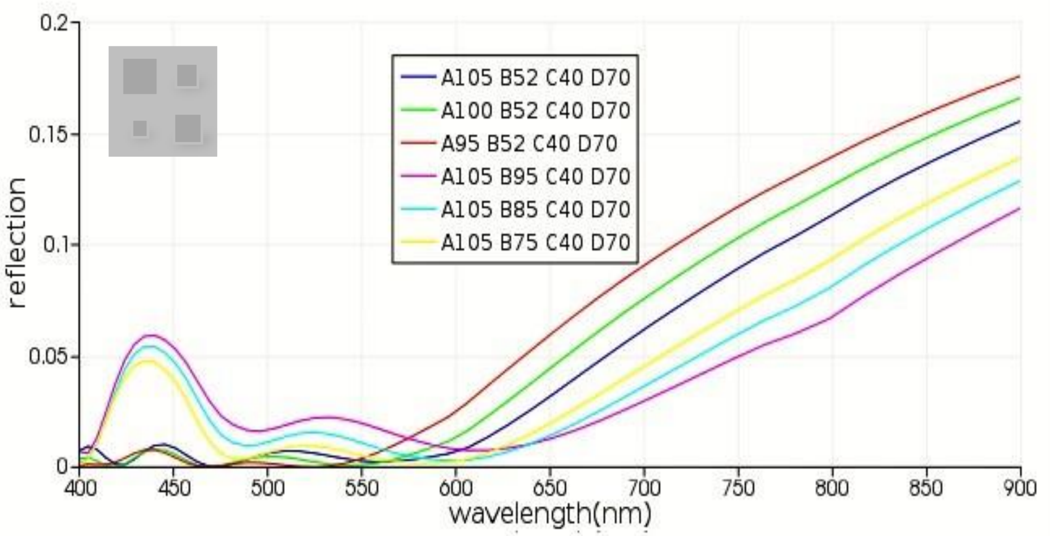
w1 = 40nm, w2=80nm, t=70nm



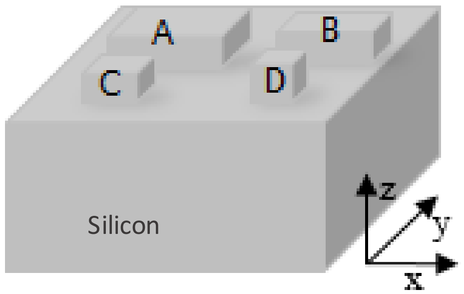
Nanopillar AR Coatings



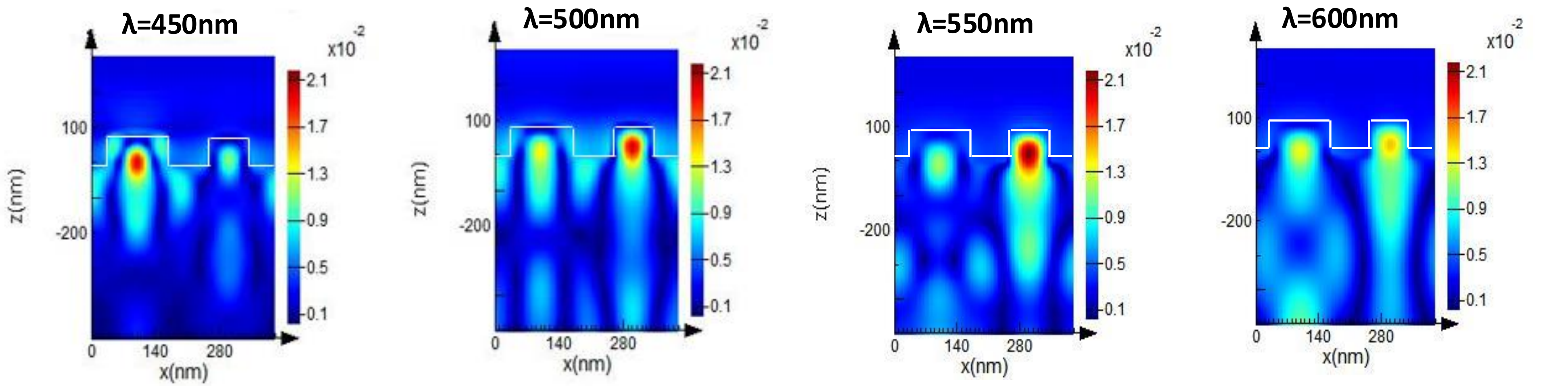
(a) Simulated reflection from the structure shown in the inset for two different pillar sizes 52nm(blue) and 80nm(green). Reflection of bared silicon is shown as reference(red). The unit cell periodicity is 217 nm.

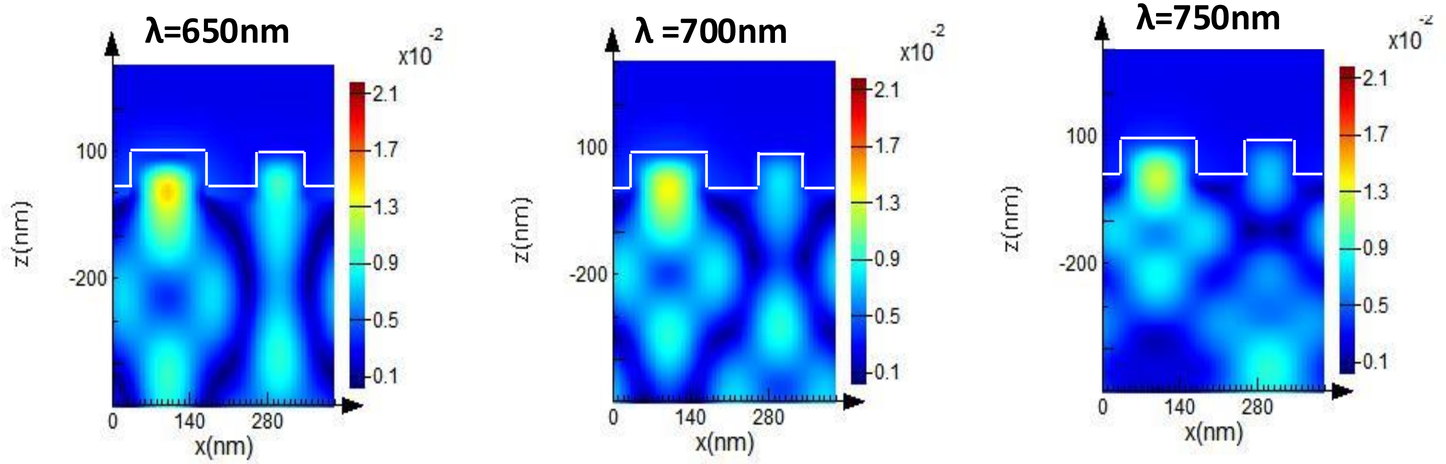


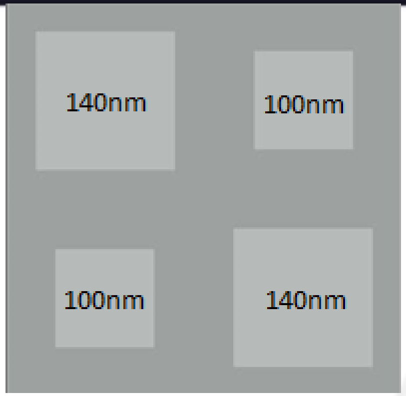
(b) Reflection spectra for four pillars(ABCD) with different width. The unit cell periodicity is 217nm. Insets are the view of the structure from XY plane.



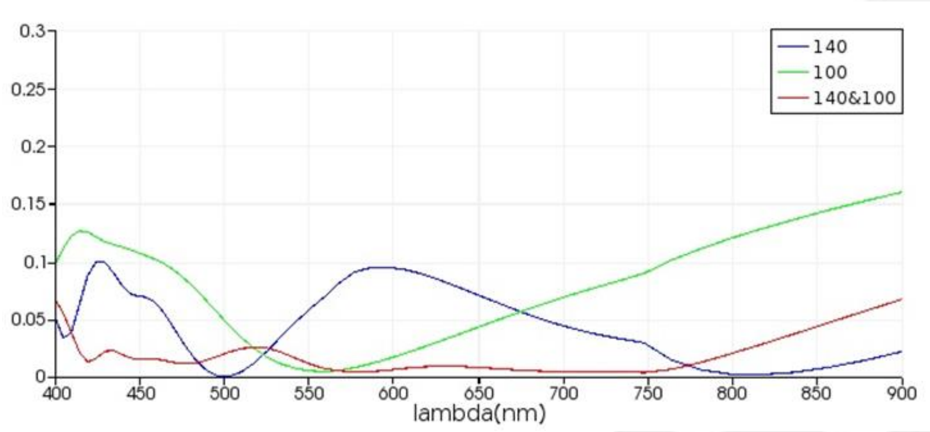
Nanopillar Field Distributions







XY plane 400x400nm



Manufacturing

Rolling Mask Lithography

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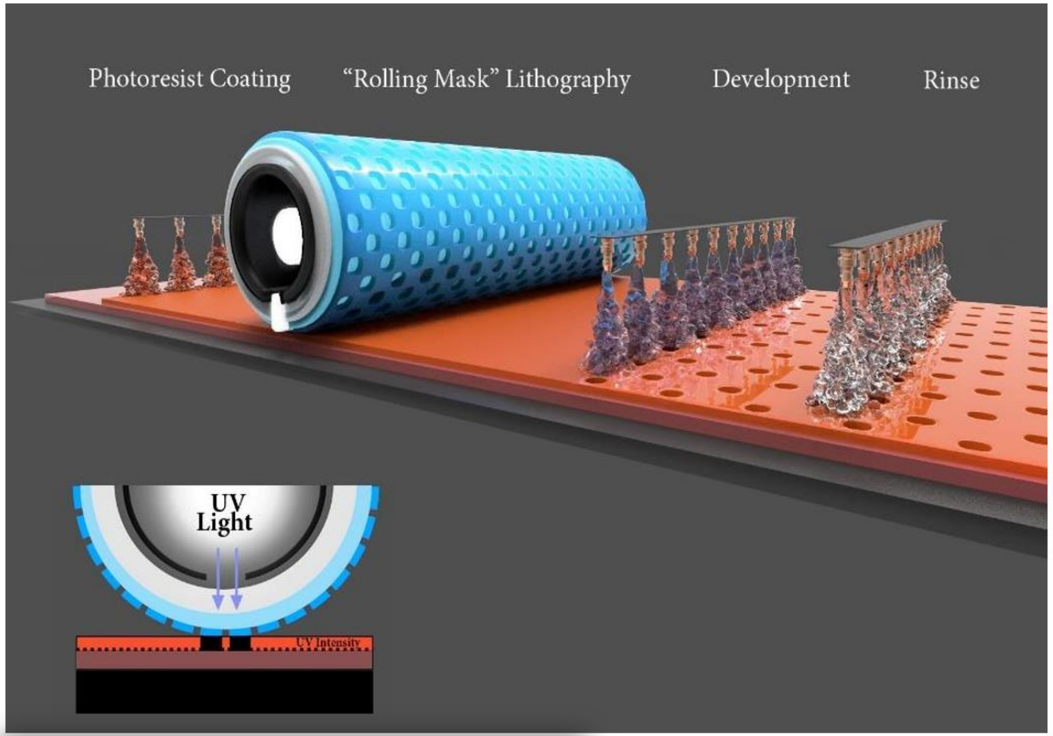
Quiz

Three frogs are sitting on a log.

One decides to jump.

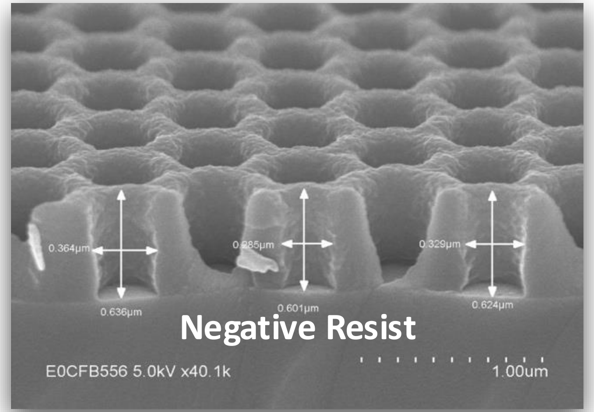
How many are left?

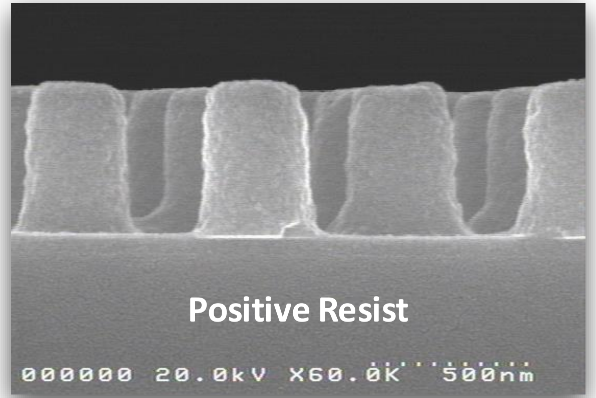
Rolling Mask Lithography - RML®

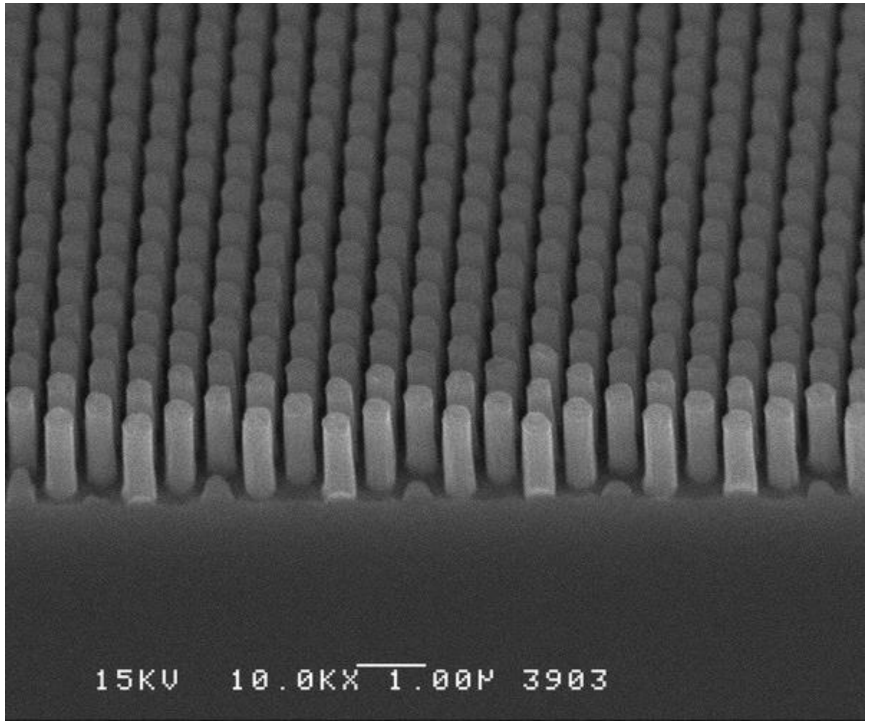


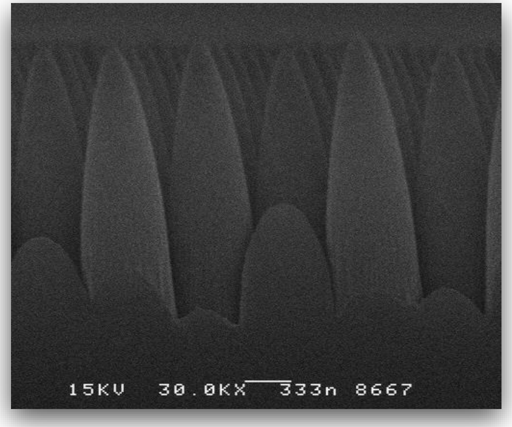
- "Rolling Mask Lithography" (RML®) - low cost, high resolution and large area nanopatterning
- Any substrate material (glass, semiconductors, flexible polymer, metal or glass films)
- Scale: up to 1m x 0.3 m (2nd Gen) and R2R continuous 1 m wide web (3rd Gen)
- Resolution: down to 150nm (2nd- Gen); 50 nm (3rd-Gen)
- Inexpensive (<$1M/tool) versus competition
- Throughput: up to 40m^2/h (3rd-Gen)
- Cost target: $5/m^2 (3rd-Gen)
- Growing IP portfolio: 22 patent families and 11 granted families

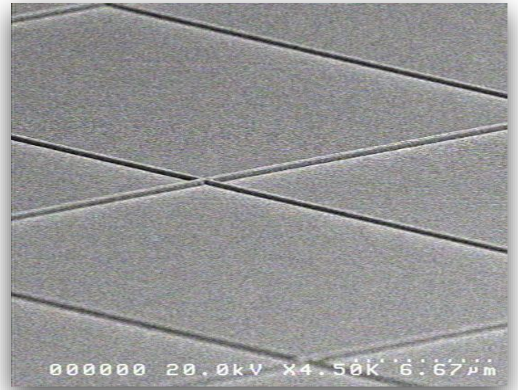
Examples of nanostructures











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Thank You

May thanks to:

Owen Mao
Mark Brongersma
NSERC